CHAPTER 6
RESULTS AND CONCLUSIONS

This chapter presents the quantitative results of the health benefits assessment for Title IV when all the pieces are put together as described in Table 2-1. First, the annual results are presented for 1997 and 2010 using the default assumptions in the calculation of changes in health effects and their monetary valuation for the eastern United States and southern portions of Ontario and Quebec, Canada. These results for 1997 and 2010 are presented in 1994 U.S. dollars and have been adjusted for expected average population growth in the United States and Canada. These results are presented as annual totals for the U.S. and Canadian study areas, with mean estimates from the distribution of the final results for each year presented as well as the 20th and 80th percentiles of the distribution. State-by-state estimates of the mean annual estimates and present value calculations for the 1995 to 2010 period are also presented. Results of some sensitivity analyses are then presented to give a sense of the directions and magnitudes of effects of key assumptions in the assessment calculations.

6.1 ANNUAL RESULTS BASED ON DEFAULT ASSUMPTIONS

Table 6-1 shows the mean, 20th percentile, and 80th percentile estimates based on the default assumptions for the 31-state eastern United States area for 1997 and 2010. Table 6-2 gives comparable results for the southern portions of Ontario and Quebec. The mean estimates are calculated using the probability distributions assigned to each health effect category, as discussed in Chapters 4 and 5. The 1997 estimates compare the annual median sulfate aerosol concentrations predicted as a result of estimated SO_2 emissions in 1997 under the Title IV requirements, with predicted banking of emissions allowances incorporated into the estimates,[1] with sulfate concentrations estimated based on 1985 SO_2 emissions. The 2010 estimates are based on predicted SO_2 emissions in 2010, after Title IV is expected to be fully implemented, versus what SO_2 emissions are predicted to have been in 2010 without Title IV but with all other provisions of the Clean Air Act in place.

[1] The banking assumptions suggest that SO_2 emissions will be lower in years between 1995 and 2000 than they would have been without banking, but that the rate of decline in emissions will be somewhat slower after the year 2000 (see Figure 3-1).

Table 6-1
Estimates of Annual Human Health Benefits of Title IV for the Eastern United States with Default Assumptions (millions of 1994 dollars)

	1997						2010					
	Annual Number of Cases Prevented			Annual Monetary Value			Annual Number of Cases Prevented			Annual Monetary Value		
Health Effect	20th Percentile	Mean	80th Percentile	20th Percentile	Mean	80th Percentile	20th Percentile	Mean	80th Percentile	20th Percentile	Mean	80th Percentile
Premature Mortality	408	2,568	5,714	$1,428.0	$9,307.2	$19,999.0	1,539	9,678	21,544	$5,386.5	$35,234.8	$75,404.0
Chronic Bronchitis (new cases)	1,648	3,864	6,590	$507.5	$974.0	$1,377.5	6,179	14,564	24,715	$1,903.0	$3,705.8	$5,165.3
Respiratory Hospital Admissions	663	805	918	$5.7	$11.3	$17.1	2,501	3,036	3,462	$21.5	$42.4	$64.6
Cardiac Hospital Admissions	510	673	867	$4.6	$9.4	$13.9	1,924	2,552	3,270	$17.5	$35.7	$52.5
Asthma Symptom Days	791,232	1,604,341	2,373,697	$20.9	$56.9	$93.2	2,983,490	5,951,693	8,950,470	$78.7	$212.9	$351.3
Restricted Activity Days (net)	1,202,785	2,467,066	3,809,253	$70.6	$147.0	$228.6	4,514,939	9,283,999	14,298,930	$265.0	$554.7	$857.9
Days with Lower Respiratory Symptoms (net)	2,028,424	5,002,393	7,259,946	$31.8	$56.7	$90.0	7,614,168	18,619,000	27,251,920	$119.3	$212.8	$338.0
Total Annual Health Benefits				$3,219.1	$10,562.3	$20,684.1				$12,131.5	$39,999.0	$77,915.5

Table 6-2
Estimates of Annual Human Health Benefits of Title IV for Ontario and Quebec, Canada with Default Assumptions (millions of 1994 dollars)

	1997						2010					
	Annual Number of Cases Prevented			Annual Monetary Value			Annual Number of Cases Prevented			Annual Monetary Value		
Health Effect	20th Percentile	Mean	80th Percentile	20th Percentile	Mean	80th Percentile	20th Percentile	Mean	80th Percentile	20th Percentile	Mean	80th Percentile
Premature Mortality	35	217	483	$122.5	$801.2	$1,690.5	37	232	517	$129.5	$839.2	$1,809.5
Chronic Bronchitis (new cases)	140	329	562	$43.3	$83.3	$117.4	150	355	601	$46.3	$91.0	$125.8
Respiratory Hospital Admissions	56	68	78	$0.5	$0.9	$1.4	60	73	83	$0.5	$1.0	$1.6
Cardiac Hospital Admissions	43	57	73	$0.4	$0.8	$1.2	46	61	78	$0.4	$0.9	$1.3
Asthma Symptom Days	66,915	133,825	200,746	$1.8	$4.8	$7.9	71,594	142,267	214,783	$1.9	$5.1	$8.4
Restricted Activity Days (net)	97,734	199,194	309,526	$5.7	$12.0	$18.6	104,568	215,270	331,168	$6.1	$13.0	$19.9
Days with Lower Respiratory Symptoms (net)	164,822	401,231	589,916	$2.6	$4.5	$7.3	176,347	433,821	631,165	$2.8	$4.9	$7.8
Total Annual Health Benefits				$273.3	$907.6	$1,746.9				$290.8	$955.0	$1,868.1

The annual estimated mean health benefits in the eastern United States (Table 6-1) for 1997 are $10.6 billion, and they rise to $40.0 billion by the year 2010. The mean estimates for Canada (Table 6-2) add an additional $908 million in 1997 and $955 million in 2010. The mean results represent the estimated annual number of cases of each type of health effect expected to be prevented as a result of Title IV versus what would have occurred without Title IV. Estimates for both years and both countries are in 1994 U.S. dollars, and have been adjusted for expected population growth based on the mid-forecasts of the U.S. Census (U.S. Bureau of the Census, 1994). Canadian population growth estimates are from World Bank population projections (Bos et al., 1992).

The health benefit estimates are dominated by the premature mortality and the chronic bronchitis effects. The numbers of cases in these health effects categories are relatively small, but the high monetary values per case result in large monetary benefits for these categories. Premature mortality reductions alone account for about 88 percent of the total health benefits. Chronic bronchitis reductions are about 9 percent of the total. The combination of the premature mortality reductions and the chronic bronchitis reductions represent about 97 percent of the total health benefits.

The largest numbers of cases reduced are for asthma symptom days, restricted activity days, and days with acute lower respiratory symptoms. The restricted activity days are net of days in the hospital and asthma symptom days because these health effects categories may substantially overlap. The lower respiratory symptom days are net of the fraction of restricted activity days that might also be attributed to lower respiratory symptoms. In 2010, the estimated mean reduction in the number of asthma symptom days because of Title IV is about 6 million in the eastern United States; the mean net restricted activity days prevented is about 9 million; and the mean estimated number of days with acute lower respiratory symptoms prevented, net of restricted activity days, is about 19 million. Together, these represent about 3 percent of the total mean monetary health benefits.

The other categories of health effects (respiratory and cardiac hospital admissions) together represent only about 0.2 percent of the total monetary health benefits. This is because relatively small risks and small monetary values combine to give relatively small total benefit amounts.

The estimates of reductions in health effects in Canada are based on estimates of changes in sulfate aerosol concentrations in Canada predicted to result from changes in SO_2 emissions generated in the United States. The estimates for Canada are primarily in the Windsor-Quebec corridor, where the greatest share of the Canadian population likely to be affected by the transport of SO_2 emissions in the eastern United States is located. The estimates for Canada represent an additional 9 percent of the Title IV benefits in 1997 estimated for the United States population. The estimates for Canada do not increase substantially from 1997 to 2010 because the estimated reductions in sulfate concentrations in Canada do not change substantially from 1997 to 2010. This is presumably because the upwind locations in the United States that affect this area of Canada see their greatest reduction in SO_2 emissions in the first phase of the Title IV program. In

2010, the estimates for Canada add an additional 2 percent to the 2010 estimates for the United States population.

Most of the selected concentration-response and monetary value estimates are based on statistically derived results. These estimates therefore have some quantified statistical uncertainty based on the estimated statistical variance in the results. For all of the health effects and monetary value estimates, low and high as well as central estimates were selected based on the estimated statistical variance and analyst judgment. In general, the selected high and low estimates represent plus and minus approximately one statistical standard error.

It is not appropriate to combine all the "low" estimates or all the "high" estimates to calculate upper and lower bounds on the final estimates, because it is highly unlikely that either all the lows or all the highs would be correct. Such extreme assumptions would significantly overstate the statistical uncertainty in the estimates. Instead, we have assigned probability weights to the low, central, and high estimates which when incorporated in the calculation process allow determination of the probability distribution of the total health benefit results.

The mean, 20th percentile, and 80th percentile estimates shown for each year in Tables 6-1 and 6-2 are the result of this procedure. All three of these estimates for each health effect category are based on the default assumptions, with each estimate representing a different selected point in the estimated probability distribution calculated for the health effect category and for total health benefits. The 20th percentile of the distribution of total health benefits for 2010 in the eastern U.S. is about $12 billion with the default assumptions. This means that 20 percent of the estimated values are below this amount and 80 percent are above it. The 80th percentile of the distribution is about $78 billion with the default assumptions. This means that 20 percent of the estimated values are above this amount and 80 percent are below it. Thus, sixty percent of the distribution of the annual total health benefits in 2010 in the eastern U.S. falls between $12 billion and $78 billion, with a mean value of $40 billion, when the default assumptions are used and the selected probability weights for each selected low, central, and high estimate are incorporated into the calculations.

Table 6-3 lists the estimated 1997 and 2010 mean annual health benefits by state and province. The per capita health benefits are calculated by dividing the total annual benefits in each state or province by the estimated 1997 and 2010 populations in each state and province (based on national average population forecasts). These give a picture of the distribution of the health benefits across the region. Five states have average annual per capita health benefits in 2010 that exceed $400. These are West Virginia, Georgia, Kentucky, Tennessee, and Alabama. Eight more states have per capita benefits between $200 and $400. These are Maryland, Delaware, Virginia, North Carolina, South Carolina, Ohio, Indiana, and Mississippi. The largest per capita benefits are thus in the Ohio River Valley, the central Atlantic states, the central and southern Appalachian states, and the eastern Gulf coast states. The lowest benefits are in the northern states of Minnesota, Maine, Vermont, and New Hampshire.

Table 6-3
Mean Estimated Health Effects Benefits of Title IV by State

State	Annual Monetary Value of Health Benefits (1994 dollars)			
	1997		2010	
	Total (millions)	Average per Capita	Total (millions)	Average per Capita
Maine, Vermont, New Hampshire	$129	$41	$128	$37
Massachusetts, Connecticut, Rhode Island	$956	$86	$580	$47
New York	$1,160	$60	$1,658	$76
Pennsylvania	$943	$74	$2,633	$183
New Jersey	$341	$41	$1,112	$119
Maryland, Delaware, D.C.	$418	$64	$1,614	$221
Virginia	$394	$59	$2,535	$339
West Virginia	$245	$127	$950	$439
North Carolina, South Carolina	$412	$38	$4,818	$394
Georgia	$765	$109	$3,508	$448
Florida	$35	$2	$2,849	$182
Ohio	$1,058	$90	$3,344	$255
Michigan	$325	$32	$1,168	$104
Illinois	$340	$28	$1,713	$124
Indiana	$512	$85	$1,515	$226
Wisconsin	$71	$13	$334	$56
Kentucky	$777	$195	$2,049	$460
Tennessee	$881	$167	$2,741	$465
Alabama	$312	$72	$1,974	$404
Mississippi	$107	$38	$654	$210
Minnesota	($72)	($15)	$88	$17
Iowa	$1	$0	$176	$52
Missouri	$242	$44	$721	$117
Arkansas	$123	$49	$285	$100
Louisiana	$87	$19	$852	$167
31-State U.S. Regional Total	**$10,562**	**$57**	**$39,999**	**$194**
Ontario	$673	$62	$789	$68
Quebec	$235	$32	$166	$21
Canadian Total	**$908**	**$50**	**$955**	**$49**

The average annual per capita estimate for all of the eastern United States for 1997 is about $57, and rises to about $194 in 2010. The average per capita benefit estimate for 1997 and 2010 in Canada is about $50, which is very similar to the 1997 average per capita estimate for the eastern United States.

6.2 AGGREGATE HEALTH BENEFITS 1997 TO 2010

The reduction in SO_2 emissions due to Title IV is expected to increase each year after 1997 until full implementation is reached in 2010. The first year for which ICF Resources (1994) reports a specific estimate for an SO_2 emissions reduction due to Title IV is 1997, when the Phase I requirements are expected to be fully implemented. The health benefits will therefore be expected to occur each year during this period, and increase each year until full implementation of Title IV is reached. The estimates of emissions reductions expected are based on a comparison of emissions expected with and without Title IV. ICF Resources reported Title IV emissions reductions estimates for 1997, 2000, 2005, and 2010.

After 2010, Title IV may continue to result in lower SO_2 emissions than would have occurred without Title IV, but projections of what emissions would have been without Title IV have not been made by EPA beyond 2010. The predicted trend in emissions for this "no Title IV" scenario up to 2010 is fairly flat, with a very slight increase in emissions from 2000 to 2010. Some analysts have predicted that after 2010, SO_2 emissions might have begun to decline even without Title IV requirements, because as old facilities are replaced, the new ones are subject to more stringent new source performance standards and other permitting requirements. However, it remains highly uncertain as to how quickly, if at all, the Title IV emissions limits would have been reached if Title IV had not been enacted.

The RADM was run for this assessment to obtain estimates of ambient outdoor sulfate aerosol concentrations in the eastern United States for 1997 and 2010 with and without Title IV scenarios. To estimate the total health benefits over the 1997 to 2010 period, annual estimates for each year in the period are needed. We estimated the annual health benefits for 1998 to 2009 using the 1997 and 2010 health benefits estimates described in the previous section and the emissions reductions estimates for 1997, 2000, 2005, and 2010 from ICF Resources (1994). We assume that health benefits occur in proportion to the emissions reductions to obtain the health benefits estimates for 2000 and 2005. For example, in the year 2000, the predicted increase in emissions reductions over the 1997 level is about 46.6 percent of the additional reduction expected by 2010 over the 1997 level (see Table 6-4: (6.38 - 4.07)/(9.03 - 4.07) = 0.466). We therefore estimate that 46.6 percent of the difference between health benefits in 1997 and 2010 will be achieved in 2000 (i.e., $10.562B + 0.466 ($39.999B - $10.562B) = $24.280B). The same procedure was used to estimate the health benefits in the year 2005. We then linearly interpolate between 1997 and 2000, 2000 and 2005, and 2005 and 2010 to obtain estimates of annual health benefits for each intervening year.

The resulting annual estimates of health benefits are reported in Table 6-4. The second column shows the estimated emissions reductions for 1997, 2000, 2005, and 2010 provided by ICF Resources. The annual health benefits estimates in the third and fourth columns for 1997 and 2010 are based on the RADM estimates of changes in sulfate concentrations under each scenario and the health effects and monetary valuation procedures as described in Chapters 4 and 5 of this report. These are mean estimates for the eastern United States and Canada based on the default assumptions. The last row shows aggregated health benefits from 1997 to 2010, in 1994 U.S. dollars, undiscounted. Undiscounted, the aggregate health benefit for this period is $404 billion for the United States and $13 billion for Canada.

Table 6-5 presents 1995 present values of total health benefit estimates from 1997 to 2010 for the eastern United States and Canada using two alternative discount rates. Given uncertainty about what the correct discount rate is for aggregating these kinds of benefits over time, we select a 7 percent rate based on OMB recommendations for analyzing government programs (OMB, 1992), and a possible lower rate of 3 percent based on evidence of a social rate of discount.[2] The discount rate has a significant effect on aggregate values over a time period as long as this so it is useful to illustrate the results using alternative rates. We have made an adjustment to each of the selected discount rates, because benefits are expected to grow over time due to increases in real income that have not been accounted for in the annual estimates presented previously. Applying discounting without making these adjustments would inappropriately downward bias the present value estimates. Expected real income growth was accounted for by deducting 0.94 percent from each discount rate based on expected annual average growth in real income from 1997 to 2010 (U.S. Department of Commerce, 1990). Real income growth is expected to increase health benefits by increasing willingness to pay for prevention of health effects. We make a rough assumption here that WTP increases in proportion to real income, although there is not sufficient empirical data to verify the accuracy of this assumption at this time. WTP could in actuality increase in either greater or lesser proportion to real income growth.

[2] Freeman (1993) presents a thorough discussion of discounting and evidence regarding appropriate discount rates for environmental programs. Alternative arguments can be made to support alterative discount rates. We select two rates from the range that is typically discussed.

Table 6-4
Mean Annual Health Benefits Estimates
1997 to 2010

Year	Estimated Reduction in Annual SO_2 Emissions Due to Title IV[1] (million tons)	Eastern United States Estimated Annual Monetary Health Benefit (millions of 1994 dollars)	Ontario and Quebec Estimated Annual Monetary Health Benefit (millions of 1994 dollars)
1997	**4.07**	**$10,562**	**$906**
1998		$15,135	$915
1999		$19,707	$922
2000	**6.38**	**$24,280**	**$930**
2001		$26,070	$933
2002		$27,859	$935
2003		$29,649	$938
2004		$31,439	$941
2005	**7.89**	**$33,229**	**$944**
2006		$34,583	$946
2007		$35,937	$948
2008		$37,291	$951
2009		$38,645	$953
2010	**9.03**	**$39,999**	**$955**
Total Undiscounted		**$404,384**	**$13,120**

[1] Based on emissions estimates from ICF Resources (1994).

Table 6-5
Total Present Value in 1995 of Mean Health Benefits
1997 to 2010 with Default Assumptions

Net Discount Rate[1]	Eastern United States (billions of 1994 dollars)	Ontario and Quebec (billions of 1994 dollars)
6.06%	$234.7	$8.2
2.06%	$333.0	$11.1

[1] The discount rates were derived as: 7.00% - 0.94% (average per capita income growth 1997-2010) giving a net discount rate of 6.06% and 3.00% - 0.94% giving a net discount rate of 2.06% (U.S. Dept. of Commerce, 1990).

6.3 SENSITIVITY ANALYSES RESULTS

There are many sources of uncertainty and potential error in the mean estimates of health benefits for Title IV reported in the previous two sections. This section presents results of some specific sensitivity analyses conducted to determine the potential effect on the results of different assumptions than those selected for the default estimates. These alternative assumptions reflect some of the key uncertainties identified in the health effects quantification and valuation chapters. The analyses reported in this section cover only the uncertainties in the concentration-response functions and in the monetary valuation of health effects. Additional uncertainties also exist in the estimates of change in SO_2 emissions and ambient sulfate concentrations that are used as inputs to the health benefits estimates. These uncertainties were discussed qualitatively in Chapter 2, but are not treated quantitatively here because these inputs are based on analyses that have been reported elsewhere.

The uncertainty and sensitivity analyses reported here are those that are reasonably amenable to quantitative treatment. It is important to recognize that there are many sources of uncertainty that are not possible to quantify, and that these sensitivity tests are therefore not a comprehensive treatment of all possible sources of uncertainty. What these tests provide, however, is an indication of how the results might change if we found that some of the key default assumptions in the health effects quantification and valuation procedures were inappropriate.

The selected sensitivity tests are based on different assumptions that we think have some nonzero probability of being accurate. A completely comprehensive range of possible results given all the uncertainties in this assessment would include zero health benefits at the low end and a very large number at the high end. That kind of comprehensive range is probably not very helpful for policy makers without some guidance in understanding the likelihood that different results within the range could be correct. We try to give this interpretation, at least qualitatively, for each of the sensitivity test results.

Each of the sensitivity tests illustrated in Table 6-6 is discussed below. They all represent estimates of mean annual health benefits for 1997 and 2010, in 1994 U.S. dollars. Each is calculated in the same way that the default mean was calculated, except for the specified assumption change. A comparison with the default means in Tables 6-1 and 6-2 therefore illustrates the effect of the change in the assumption.

Health Effects Thresholds

As discussed in Chapter 4, there is considerable uncertainty about whether there is a "safe" level of sulfate aerosol exposure that does not cause any harmful health effects. There is no definitive quantitative evidence that such a threshold exists, but neither is there proof that any amount of sulfate aerosol exposure causes some harmful effect in at least some people. We selected three possible threshold levels to illustrate how this could affect the results. The existence of a threshold could only decrease, not increase, the results because it means that further reductions in sulfate levels in areas that are already at or close to the threshold would not yield any health benefits.

We selected alternative threshold assumptions of 5.0 $\mu g/m^3$, 3.6 $\mu g/m^3$, and 1.6 $\mu g/m^3$ annual median SO_4 concentrations to illustrate the potential effects of alternative threshold assumptions on the results of this analysis. As discussed in Chapter 4, none of these concentrations has been identified as a true threshold, but each represents a mean or low end value for the range of concentrations considered in one of the epidemiology studies that concentration-response functions were taken from. The threshold calculation was implemented as follows. Any RADM grid cell with a base case 2010 (without Title IV) level of annual 50th percentile SO_4 at the threshold concentration or less was assigned zero health benefits for the Title IV emissions reductions.[3] Further, health benefits were calculated only for reductions in annual 50th percentile down to the threshold. For the 5.0 $\mu g/m^3$ threshold, for example, if the level without Title IV was 5.5 and the level with Title IV was 4.5, the health benefits calculations for that grid cell were made only for the 5.5 minus 5.0 reduction of 0.5. Any additional reduction below 5.0 was presumed to provide no health benefit.

The results indicate that with a threshold of 5.0 $\mu g/m^3$ SO_4, annual health benefits are substantially reduced relative to the default mean, falling very close to the 20 percentile estimates. At thresholds above 5.0 the health benefit estimates would diminish even more. A threshold of 3.6 $\mu g/m^3$ SO_4 results in a health benefit estimate that falls about midway between the default mean and the 20 percentile default estimates. At a threshold of 1.6 (or lower), the health benefit estimate is virtually unchanged from the default mean. This illustrates the significance of the threshold question and shows that this continues to be an important research issue from the standpoint of evaluating the health benefits of pollution emission reductions.

[3] RADM estimates that in a few locations sulfate concentrations will be higher with Title IV than without Title IV. In general, these places have very low sulfate concentrations and may fall below the threshold concentration under consideration. Because a cell below the threshold concentration is assigned zero health benefits, no negative health benefits are calculated in the threshold analyses. This is why the 1997 results using the 1.6 threshold assumption slightly exceed the mean results when no threshold is assumed.

Table 6-6
Sensitivity Analyses Results

Assumptions	Estimated Annual Health Benefits (billions of 1994 dollars)
United States 1997	
Threshold = 5.0 $\mu g/m^3$ SO_4	$3.1
Threshold = 3.6 $\mu g/m^3$ SO_4	$6.7
Threshold = 1.6 $\mu g/m^3$ SO_4	$10.8
Selected SO_4 Health Risks × 0.4	$4.8
United States 2010	
Threshold = 5.0 $\mu g/m^3$ SO_4	$15.0
Threshold = 3.6 $\mu g/m^3$ SO_4	$28.3
Threshold = 1.6 $\mu g/m^3$ SO_4	$39.3
Selected SO_4 Health Risks × 0.4	$18.5
Canada 1997	
Threshold = 5.0 $\mu g/m^3$ SO_4	$0.0
Threshold = 3.6 $\mu g/m^3$ SO_4	$0.0
Threshold = 1.6 $\mu g/m^3$ SO_4	$0.7
Selected SO_4 Health Risks × 0.4	$0.4
Canada 2010	
Threshold = 5.0 $\mu g/m^3$ SO_4	$0.0
Threshold = 3.6 $\mu g/m^3$ SO_4	$0.0
Threshold = 1.6 $\mu g/m^3$ SO_4	$0.9
Selected SO_4 Health Risks × 0.4	$0.5

Lower Health Risks for Sulfates

As discussed in Chapter 4, there is a possibility that the sulfate based concentration-response functions may be somewhat upwardly biased because of the typical collinearity between sulfates and other fine particulate constituents in the ambient air. For this sensitivity test we multiply the sulfate based concentration-response functions by 0.4, which is the average ratio between measured sulfates and measured $PM_{2.5}$ in the eastern United States. This is the maximum

adjustment that would be required if the sulfate coefficients represented the total effects of all $PM_{2.5}$. This adjustment reduces the annual health benefit estimate to about $18.5 billion, in 2010, which is higher than the 20th percentile estimate with the default assumptions. The true sulfate effect is probably between this and the mean default estimate because the sulfate coefficients probably do reflect some, but are unlikely to reflect all, of the effects of other harmful constituents of $PM_{2.5}$ as well as the effects of sulfates alone.

6.4 CONCLUSIONS

The results of this assessment show that the potential health benefits of reductions in exposures to sulfate aerosols in the eastern United States as a result of the SO_2 emissions reductions required by Title IV are substantial. Based on what we believe is a reasonable interpretation of the available epidemiology and economic evidence on potential health effects of sulfate aerosols and their monetary value, we estimate that the annual health benefits of Title IV required reductions in SO_2 in 2010 in the eastern United States are more likely than not to fall between $12 billion and $78 billion, with an estimated mean value of $40 billion. There is reason to expect some possible upward bias at the higher end of this range, and the results of the sensitivity analyses suggest that there is a good chance that the benefits in 2010 fall between $12 billion and the estimated mean of $40 billion. Annual health benefits for eastern Canada resulting from U.S. reductions in SO_2 emissions would add as much as one billion dollars to the U.S. benefit totals in both 1997 and 2010.

We have been careful throughout the report to highlight key assumptions and uncertainties that exist in the quantification procedures used in this assessment, especially in the health effects quantification and valuation portions of the assessment which are the focus of this report. Most of these uncertainties cannot be resolved without substantial new research on several topics. The most important empirical uncertainties in the health effects quantification are:

- What is the relative harmfulness of sulfate aerosols versus other fine particulate matter?
- Is there a threshold for health effects from sulfate aerosols, and if so, what is it?
- Is there sufficient evidence to presume that the observed association between sulfate concentrations and human health effects is causative?

The most important uncertainties in the monetary valuation of health effects are:

- Are WTP estimates for risks of accidental deaths in populations of average health status applicable to premature mortality risks associated with air pollutant exposures?

- How do WTP values for premature mortality and other health risks vary for the elderly and for those whose health is already poor?

- Will the available WTP estimates for chronic respiratory disease be verified by new WTP research?